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COMBAT ALLOCATION AND FUTURE COMBAT TASKS--STATUS REPORT, FY 19--ETC(U)
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Future Combat

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(6) COMBAT ALLOCATION AND FUTURE COMBAT TASKS--STATUS REPORT, FY 1962,

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COMBAT ALLOCATION AND FUTURE COMBAT TASKS--STATUS REPORT, FY 1962

BRIEF

REQUIREMENT:

USCONARC and DCSPER have a requirement that means ^{must} be devised for estimating military personnel needs of the future, with particular emphasis on needs arising in connection with proper utilization of personnel in combat organizations. The research objective is being pursued in conjunction with later stages in developing an allocation system to insure that the total contribution of personnel entering the Army is maximized both in combat and combat support activities. 7

PROCEDURE:

During FY 1962, a research effort was initiated to devise a system of information flow and analysis by which manpower requirements of projected weapons systems can be assessed with adequate specificity. This effort is conducted in cooperation with a committee established by the Office of the Chief of Research and Development with the objective of insuring systematic consideration of human factors during development of hardware systems.

At the same time, mathematical models are being developed for describing manpower resources in multivariate terms so that estimated future needs and future supply can be compared and probable discrepancies identified. Research has been initiated to determine requirements for adequate experimentation early in the hardware development sequence. Particular attention is being paid to minimum size of experiment consistent with sufficient power to detect predictor validity or other effects when, in fact, they exist.

FY 1962 effort in the COMBAT ALLOCATION Task centered on final stages in developing a practicable computerized system for optimal classification and assignment of basic training graduates for various kinds of advanced training.

ACCOMPLISHMENTS TO DATE:

→ Trial application of the computerized optimal allocation methods developed to an actual input sample showed that marked increase in average aptitude levels could be attained in both combat and combat support jobs, and that all EM would have the qualifications prerequisite to MOS to which allocated by the system. Appropriate content and format of qualitative and quantitative personnel requirements are being developed for inclusion in an Army Human Factors Handbook for use through all stages of weapons development.

UTILIZATION OF FINDINGS:

The potential military end result is a means of obtaining and formulating estimates of total future Army personnel requirements within specified time

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frames, including personnel requirements arising from new and projected weapons systems. When estimates are compared with future availability estimates, probable critical areas of personnel shortage and overage can be identified.

Improvements in management of the Army's human resources are expected through application of the computerized allocation system developed.

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COMBAT ALLOCATION AND FUTURE COMBAT TASKS--STATUS REPORT, FY 1962

For many years an accepted feature of the Army distribution system has been the selection of the best available talent for jobs requiring technical attributes. While difficult, technically complex Army school courses undeniably require high caliber students, it is true as well that able men are required for combat duties. Not only are requirements for specialists in the supporting services constantly increasing, but the job of the combat soldier is becoming more demanding as the military establishment progressively adapts itself to the new requirements of atomic warfare. Increased complexity of equipment and weapons systems and a heightened mobility and independence of action in dispersed formations place greater demands than ever before on the combat soldier.

The increasingly delicate balance between combat and support services in their requirements for able personnel underscores the importance of effective and economical distribution of ability, as well as the need for care and system in planning future uses of personnel. Aware of existing and potential manpower problems, the U. S. Army Personnel Research Office has been conducting two research tasks which address themselves to two aspects of manpower economics --manpower distribution and manpower planning.

THE COMBAT ALLOCATION TASK

HISTORICAL DEVELOPMENT

Since World War II, personnel research effort has been responsible for continuous improvements in techniques for classifying and assigning enlisted personnel in the Army. From the use of a single general mental ability test in World War II, the Army progressed to the aptitude area system of classification. Ten tests, each designed to measure a different aptitude or skill important in one or more types of Army job, were assembled into different combinations to provide a comprehensive classification scheme. Further research from 1949 to 1955 resulted in a streamlined aptitude area system, including test combinations for use as combat selectors. Early in 1958, an important modification was introduced--two new tests and two new aptitude areas, tailor-made on the basis of extensive Korean combat research to identify more of the specific kinds of manpower needed by the combat areas.

The intent of these improvements in the Army's classification system was to increase the Army's overall effectiveness. Identifying personnel who will perform well in a variety of Army jobs, however, is only a part of the approach to the objective. Successful identification of talent needed by the Army does not guarantee distribution of such talent to the various military occupational specialties in accordance with the needs of the military service. When many different aptitudes of each individual must be considered in relation to many different Army jobs, the distribution problem becomes highly complex. In short, full benefits of the classification system cannot be realized unless the distribution system receives equal attention.

USCONARC in FY 1957 requested research on the allocation problem. Particular emphasis was to be placed upon improved allocation to combat MOS, taking care not to permit a swing of the pendulum to the side of inequitable allocation to the supporting services. USCONARC was seriously concerned that the quality of manpower being supplied to combat divisions was lower than that supplied to the rest of the Army. Accordingly, a study was undertaken to find how aptitude levels in combat divisions compared with aptitude levels in the Army as a whole.

SURVEY OF APTITUDE AREA SCORES IN COMBAT DIVISIONS

Data for the combat divisions were obtained from a survey of six Pentomic divisions--two infantry divisions and one armored division in the Zone of the Interior, and two infantry divisions and one armored division stationed overseas. Enlisted men who had entered the Army prior to introduction of the aptitude area system were excluded from the study, as were also aliens, leaving a sample of about 9,500 men. For comparison purposes, total Army statistics were also obtained or estimated using data taken from a Sample Survey of Military Personnel (RSC AG 366) as of 30 September 1957. Aptitude area mean scores for the total Army were found to exceed those for the combat divisions by about two points. In no aptitude area did the mean score for the combat divisions exceed the corresponding mean score for the total Army. Considering that about one-half the Army strength was in combat organizations, the difference between the mean aptitude scores for the combat personnel and for the rest of the Army--excluding the combat arms--was calculated to be at least four points. The concern of USCONARC was thus found to be well grounded: the quality of manpower in the combat arms was substantially below that of the rest of the Army.

Considering only the combat division personnel, the average combat aptitude of men with first primary MOS in a combat occupational area was found to be on the average six points below the combat aptitude area score of men in other occupational areas. In fact, combat division personnel initially assigned to training in MOS other than combat were of higher quality than those in the Army as a whole. It was therefore clear that the relatively low quality of men being assigned in the combat occupational area was responsible for the low aptitude level of the combat divisions.

IMPROVED MECHANIZED ASSIGNMENT SYSTEM NOW IN EFFECT

The situation was somewhat alleviated in October 1958 when an electrical accounting machine system (EAM) of making assignments by name was put into effect. Under this system an increased amount of relevant information about the individual soldier was made available for use in determining individual training assignments after completion of Basic Combat Training. The information includes name, service number, all six digits of the physical profile, aptitude area scores (reported in intervals), years of education, and service relevant high school courses. Under the older system, the only data supplied were the number of individuals having a given physical profile and a given "most appropriate aptitude area" and ranges of aptitude area scores

for the group reported. This system, with only minor modifications, has resulted in substantial gain in the relative quality of personnel assigned to Advanced Individual Training in combat MOS.

CONCEPTUAL DEVELOPMENT OF AN ALLOCATION SYSTEM

While the machine-implemented system introduced in 1958 constituted a substantial improvement over the older system, USAPRO personnel recognized that an optimal system for allocating personnel would require use of stored-program computing equipment. There had been for some years a considerable body of economic and applied mathematical literature dealing with the optimal utilization of resources in the face of scarcity. Mathematical statement of certain optimization problems had been accomplished, and techniques for solving the stated problems had been developed. Applied mathematicians themselves had realized that segments of the logic which they were developing were also applicable to the problem of assigning many people to many jobs. Thus a considerable body of material was available from which to structure a computerized optimal classification system.

A significant segment of this literature dealt with the solution of the classical Hitchcock-Coopman transportation problem which may be mathematically stated as follows:

Let c_{ij} be the unit cost of shipping a commodity from location i to location j .

x_{ij} be the number of units of the commodity to be shipped from location i to location j .

$z = \sum_i \sum_j x_{ij} c_{ij}$ be the total cost of shipping incurred for a given set of x_{ij} .

P_i be the amount to be shipped from location i .

Q_j be the amount needed at destination j . (The problem has the restraint that $\sum_i P_i = \sum_j Q_j$).

The transportation problem, then, is to minimize the value of z subject to the linear restraints:

$$\sum_j x_{ij} = P_i$$

$$\sum_i x_{ij} = Q_j$$

$$x_{ij} \geq 0$$

Mathematically, the personnel assignment problem takes on similar form:

Let c_{ij} be the value of the i th man if placed on job j .

x_{ij} be one if man i is to be assigned to job j , zero otherwise.

$z = \sum_i \sum_j c_{ij} x_{ij}$ be the total value of a particular set of assignments.

Q_j be the number of people assigned to job j .

In this statement of the assignment problem, the value analogous to P_i in the transportation problem is one, since a man can be assigned to one and only one job. The assignment problem is, then, to maximize z subject to the linear restraints:

$$\sum_i x_{ij} = Q_j \quad (2)$$

$$\sum_j x_{ij} = 1 \quad (2a)$$

$$x_{ij} \geq 0 \quad (2b)$$

Note that restraint (2b) states that the x 's should be positive whereas the actual requirement is that x be zero or one. This statement is sufficient, however, as it has been shown that if the row and column sum restrictions on x are integers, then the optimum set of x 's will be a set of integers (Gass, 1958). Clearly, the only integers that can satisfy both (2a) and (2b) are zero and one.

In the Army situation, however, the set of restraints (2) are not sufficient. There are jobs for which the man may not be qualified by virtue of the fact that he does not satisfy certain overriding prerequisite considerations. For example, he may be color blind and hence not eligible for training in certain electronic MOS. In this case, additional restraints are imposed:

$$x_{ij} \leq b_{ij}$$

where b_{ij} is one if the man is eligible, zero otherwise. (3)

Traditionally, the optimization of z under the entire set of restraints (2) and (3) is referred to as the capacitated transportation problem. An efficient algorithm for solving this problem has been devised by Ford and Fulkerson (1956). This algorithm is such that the x 's will take on only the values of zero and one to indicate assignment or nonassignment. This algorithm has the feature that infeasible requirements are identified, that is, when the prerequisites defining the b_{ij} are so stiff that quotas cannot be met, the algorithm yields a result indicating that such is the case.

Under the existence of the Ford-Fulkerson algorithm, and presuming that feasible body requirements can be stated for a given group of personnel to be allocated, then the conceptual means for solving the personnel distribution problem are known, with the exception that a working definition of the c_{ij}

must be supplied. It is in this respect that the previously discussed aptitude area system comes into play, since this system affords the best means available for predicting early in the enlisted man's career his ability to perform adequately in the various Army specialties. A long history of development and intensive study has resulted in the status of the aptitude area system as the most thoroughly validated means of predicting Army performance. In practice, then, the a_j is defined by man i 's score on that aptitude area which has been established as the selector for job j . When this is done, maximization of the average aptitude of the men for the jobs to which they are assigned within the restraints of body requirements and minimum prerequisites may be accomplished.

DEVELOPING A WORKING SYSTEM

Having set out a conceptual statement of the problem, the next step was to begin development of an operationally feasible system. Operating requirements were developed under the following assumptions:

1. Assignments would be generated using stored program equipment, either the IBM 705 digital computer or the IBM 1401.
2. EM would be allocated by blocks corresponding to the weekly population of graduates from Basic Combat Training.
3. Detailed input for each man would be in the punched card form specified in AR 611-259, Personnel Selection and Classification: Basic Trainees Available for Advanced Individual Training.
4. The program would deal with all US and RA unassigned personnel who are not subject to special disposition, Scientific and Engineering personnel, for example. EM with Army Career Group or school commitment would not be handled by this program.
5. Job quotas would be supplied for the population handled by the program. Vacancies filled by personnel with enlistment commitment would have been subtracted from the quotas supplied.
6. Total quotas supplied would have been so developed that the computer would not be dealing with a shortage or overage situation.
7. The following points of flexibility would be required:
 - the specific jobs to which personnel were to be allocated
 - the job quotas
 - the minimum prerequisites
 - the size and composition of the population to be allocated.
8. The product to be generated is a list of training recommendations for the Basic Combat Training graduates processed.

Under these assumptions, system analysis and programming were begun. Program possibilities were considered both for the IBM 705 and for the IBM 1401. The 705 program was initiated in FORTRAN symbolic language, while the 1401 approach utilized basic machine language. The advantages of working in the basic language, on a problem of the present magnitude, were soon apparent. As soon as feasibility was reasonably well established, the decision was made to restrict attention to the IBM 1401.

The procedure used in solving the assignment problem consists of an initial examination of the detailed information on each EM under consideration to determine the jobs for which he is eligible. This is done for all men and for all jobs. On jobs for which eligibility obtains, the c_{ij} value is assigned.

This value corresponds to a numerical code for the interval in which a man's score is found to lie. Jobs for which he is ineligible are marked as such. The machine then proceeds through an iterative procedure by which a set of assignments is made. If these assignments meet the quotas, the machine stops; if not, certain modifications are made in the matrix of c_{ij} and assignments are modified until finally the quotas are met.

The iterative procedure differs considerably from the Ford-Fulkerson algorithm which, it was felt, was not well suited for use on the data processing type of computer available for this purpose. Rather, a method called the Method of Optimal Regions (Brogden, 1954; Dwyer, 1957) was used because it requires fewer iterations and allows certain operations to be accomplished on a man-for-man basis, thus speeding up the processing operation.

The 1401 program evolved through a series of modifications until a program was developed which would handle up to 100,000 men to be assigned to 300 jobs. Input data consist of detail cards as described in AR 611-259, maximum and minimum quotas for jobs to which assignments are to be made, and minimum prerequisites in force at the time assignments are to be made. Assumptions 2, 4, 5, and 6 are considered to have been met by appropriate choice of detail card input and by proper calculation of quotas. The program, by its own construction, meets the requirements imposed by assumptions 1, 3, and 7. Additionally, a provisional output format has been devised which is appropriate only for research purposes. An output for operational use would be developed at such time as the program is ready for implementation.

APPLICATION OF THE SYSTEM

The 1401 program was used to accomplish a trial allocation of 5128 EM processed through Replacement Branch in late January of 1962. Cards had been initially screened to eliminate EM who should be handled by special procedures (such as Scientific and Engineering personnel, conscientious objectors, and personnel with enlistment commitments). Detail cards and quotas were supplied by Replacement Branch, TAG. Minimum prerequisites for school courses were taken from the Army School Catalog (DA Pam 20-21). For non-school courses, requirements were prepared by personnel of the Systems Development Branch, TAG R and D Command. The additional prerequisites have since been submitted as a proposed Annex 5 to the Army School Catalog.

Only 31 configurations of prerequisites were required for the particular population at hand--though more jobs were actually involved. All the jobs were therefore grouped into the 31 categories to minimize machine running time. Such grouping would probably be done in operational use of the program.

Using the USAPRO program, the trial allocation was accomplished in four hours. All but 18 of the men were provided for. Of these 18, 11 were unassignable because of inadequate aptitude area score levels, six because of inadequate PULHES; one card was found to be blank. In cases like these, the computer prints out detailed information on the unassignables, who must be handled separately.

Table 1 affords a means of evaluating the computer-generated assignments. Entries consist of mean scores on the aptitude areas appropriate to the assignment obtained. Means in the left-hand column were obtained from the machine run under discussion, those in the second column from EAM-generated assignments. The third column presents means actually observed in the previously mentioned survey of combat divisions. This third column is to some extent representative of the distribution situation prior to the introduction of EAM equipment.

The general trend of the means presented is indicative of the advantages of automated allocation procedures. Use of EAM equipment has resulted in generally improved assignments as compared with the antiquated hand-processing systems. Additional gains can be made through use of stored-program equipment and more sophisticated methods.

Table 1

MEAN SCORES ON SELECTOR APTITUDE AREA ATTAINED BY PERSONNEL ALLOCATED
UNDER DIFFERENT PROCESSING PROCEDURES

Aptitude Area on Which Selection is Based ^a	Allocation Procedure		
	Computer	EAM	Manual
Infantry (IN)	109	98	97 ^b
Artillery-Armor-Engineer (AE)	111	102	99 ^b
Electronics (EL)	120	112	107
General Maintenance (GM)	117	105	100
Motor Maintenance (MM)	118	109	109
Clerical (CL)	114	114	112
General Technical (GT)	121	103	101

^aRadio Code means are not included because of the large number of unsatisfactory scores.

^bMeans of now obsolete Combat Aptitude Areas CO-A and CO-B obtained in the combat division sample. These areas are now no longer in use, having been supplanted by two new combat aptitude area composites.

Table 2 provides another way of considering the same sets of data, that is, in terms of percentages of men assigned to aptitude areas for which they had a score of less than 90. The score of 90 is a commonly accepted benchmark for summary statistics of this type. Results indicated the marked gains to be made by progressively more sophisticated automation. The only two MOS to which the computer assigned anyone below 90 in the requisite aptitude area were Supply Handler (550) and Food Service Helper (940), both MOS for which no minimum scores have been set.

Table 2

PERCENT BELOW 90^a ON APTITUDE AREA OF SELECTION
AMONG PERSONNEL ALLOCATED UNDER DIFFERENT PROCESSING METHODS

Aptitude Area of Selection ^b	Allocation Procedure		
	Computer	EAM	Manual
Infantry (IN)	0	14	30 ^c
Artillery-Armor-Engineer (AE)	0	15	33 ^c
Electronics (EL)	0	0	22
General Maintenance (GM)	3	26	29
Motor Maintenance (MM)	0	0+	12
Clerical (CL)	0	0+	40
General Technical (GT)	2	7	24

^aWhere a plus is recorded with a zero it means that while some cases below 90 were assigned in the area, the percentage rounded to zero. Unplussed zeros are true zeros.

^bRadio Code percentages are not included due to large number of unsatisfactory scores.

^cPercentages refer to now obsolete CO-A and CO-B aptitude areas obtained on the combat division sample. These areas have been supplanted by two new aptitude area composites.

Some caution should be exercised in interpreting Tables 1 and 2. The means and percentages presented are derived from differing samples with different

quotas, obtained at different times and under somewhat different minimum prerequisites. Entries in the tables provide a clear indication of the trend in favor of increased automation, but are not to be taken as a summary of the general state of affairs in the Army at any given time. The figures are, however, sufficient for the purposes of the present report, indicating as they do the direction of superiority of the various allocation techniques.

Note that in the data presented above the goodness of assignment is evaluated essentially in terms of aptitude area scores and does not contain reference to personnel preferences or interviewer recommendations. Both these variables are available on the detail card in the form of an MOS for which the trainee expresses preference to an interviewer, as well as the MOS which the interviewer feels is appropriate. USAPRO has not to date considered including these variables as bases for assignment or as means of assessing the assignments. The balance of psychological research evidence from industry and in other job-choice oriented contexts supports the notion that objective psychological measurement of the test-questionnaire type constitutes a basis on which to make predictions of job performance superior to either expressed preference or interviewer recommendations. It is therefore felt that expressions of interest and interviewer judgments should be considered only after systematic formal research has been conducted to determine whether additional predictors would contribute to the predictive efficiency of the Classification Battery and what format should be used for such predictors. Since aptitude area scores are the best-validated predictors of Army school and job performance in existence, it is felt that assignments should be generated and assessed in terms of these scores, as was done in the study reported.

FUTURE RESEARCH ON COMBAT ALLOCATION

During FY 1962, USAPRO and the Engineering Systems Branch of TAG Data Processing activity, now USADSC, established a joint effort in respect to the assignment of non-prior service personnel. USADSC had at the time--and still has on its books--projects to automate the processing of records of non-prior service personnel. The 1401 program developed by USAPRO would constitute a subroutine in such an automated system, and will be made available. Additionally, USAPRO has worked successfully with USADSC personnel on another automation project (TAGOP No. 62-58). Representatives of the two organizations are working cooperatively at developing and implementing automation, where feasible, of the entire processing of EM from basic training to advanced training. It is hoped that a feasible and adequate system will be in implementation by 1 January 1963.

Since the above cooperative effort constitutes primarily the development of a data processing system, the effort is not considered to merit task status. Accordingly, the Combat Allocation Task is terminated as of the end of FY 1962. Remaining work on the automation phase of this effort is being conducted during FY 1963 as a subtask of the Future Combat Task.

FUTURE COMBAT TASK

The Combat Allocation Task was mainly concerned with operations in the area of manpower distribution. This is an area characterized by recurring operational problems which may be approached by analyzing and improving, where possible, recurrent management procedures. By contrast, the Future Combat Task deals with problems removed from the sphere of immediate need to which current procedures may not even address themselves. These problems are associated with change in the character of the manpower supply required as a function of change in the structure or scope of operation of the Army. The objective of the task, stated in more general form, is to provide information by which future manpower problems may be anticipated. The task aims to set up, where possible, regular channels for information flow, to insure that procedures are established whereby future manpower problems may be routinely identified, and to provide research answers to problems as they are detected--or at least to state the problems in researchable form.

EVOLUTION OF TASK MISSION

The task has its origins in a research study conducted by USAPRO personnel (King and Boldt, 1959). The study was responsive to a USCONARC recommendation, made at the April 1959 meeting of the Army Human Factors Research Advisory Committee, that USAPRO (at that time the Personnel Research Branch) undertake "a survey of technical aptitudes and critical skills that the Army might require or expect from the National Manpower Pool during the next ten years." This recommendation was modified by the Committee to a request for a research study, to include a survey of Department of the Army programs concerned with estimation of future personnel requirements. The study was also to outline dimensions of the overall problem of improving Army personnel forecasting and planning, taking into account future Army weapons systems.

One of the problem areas identified in the research study was that "inadequate provision has not been made for determining human factors requirements of new weapons systems." With this and related problems in mind the Future Combat Task was proposed, accepted, and established.

At the outset, considerable effort was expended in identifying broad research areas that would be at once within the scope of the task objective and amenable to investigation within limitations of resources at hand. It was anticipated that a content analysis of Qualitative Materiel Requirements (QMR) would lead to identification of broad classes of equipment to be produced in such quantity as to have a significant effect on the character of manpower required by the Army. However, inspection of particular QMR's revealed that the documents do not contain human factors information of sufficient specificity to be useful for the purpose. Accordingly, a search was made for other channels by which to identify equipment which would have significant manpower implications. To this end, coordination was effected with other human factors agencies through the Human Factors Research Division, OCRD. As a result of contacts established, attention was turned to the

problem of developing channels of information flow for use in requirement and training program development.

ESTABLISHMENT OF A COORDINATED HUMAN FACTORS EFFORT

On 7 March 1962, USAFRO received from the Chief, HFRD a letter requesting participation of USAFRO in a "research program to develop Army Human Factors guidelines for assuring systematic consideration of human factors matters early in the development process for new weapons systems and other materiel." The participation fell to personnel of the Future Combat Task.

To initiate the program, a group of research scientists was formed consisting of representatives of USAFRO, the Human Resources Research Organization (HumRRO), and the Human Engineering Laboratories (HEL). The group began work with a series of conferences with DCSPER, TAG, USCONARC, and also inquired into Air Force practices. At one outset the group decided that the Air Force Systems Command Manual 80-3, Handbook of Instructions for Aerospace Personnel Subsystem Designers, would serve as an appropriate point of departure for the Army in incorporating human factors considerations in materiel development. A similar handbook tailored to Army needs, and possibly having regulative force, could serve the needs of OCRD and provide a vehicle for insuring a flow of information adequate to foreshadow future manpower problems.

Among the topics tentatively projected for the Handbook are: human engineering, qualitative and quantitative personnel requirements information, the training concept, development of training equipment, training plans, required technical publications, personnel subsystem test and evaluation. Under each topic, various phases in the development of hardware will be treated, with emphasis on application of most appropriate procedures and the formulation of useful information. The information relating to qualitative and quantitative personnel requirements will be used to establish ahead of time the manpower demands incurred by adoption of a given system. Training information and concept development in the Handbook will be useful for assuring that training courses and equipment will be ready in time to provide a supply of properly trained personnel to operate the system when it reaches field status. Human engineering and testing phases will deal with procedures which must ideally be followed to insure that the system can be handled effectively by appropriate Army personnel.

Members of the committee have been gathering information about current Army practices and have reached the point where procedures desirable in the Army context are being outlined. The work has proceeded on an almost daily cooperative basis between USAFRO and HumRRO with periodic meetings with the HEL representative. Once personnel and training information needs are more thoroughly specified, the involvement of HEL is expected to become more extensive.

HOW PERSONNEL REQUIREMENTS INFORMATION CAN BE USED

The effort described above would lead to the establishment of channels of information flow both to a DCSPER-type activity and to other interested organizations. The conclusion appears unavoidable that the manpower requirements of new weapons systems must be gathered into one central file of requirements and a procedure established for assessing their total impact. To this end, the requirements must be stated in terms of characteristics of people. Requirements may then be compared with anticipated characteristics of the personnel supply. Such comparisons will be possible only if adequate descriptive tools are available. The problem attacked was that of developing conceptual tools suitable for describing Army populations in such a way that deductions may be made on a regular basis, without undue involvement in difficult and expensive computing procedures.

In this vein it was possible to make a fairly precise statement of the kind of manpower problem which might arise: Given a set of jobs and their respective body requirements, can a supply population described in a specified way be allocated to the jobs in such a way as to satisfy the requirement? If the answer is "No," a future personnel problem has been identified. To answer such a question, minimum values are first determined for prerequisite variables for each job in question. The supply population is described in terms of these variables, and the number of persons available for each combination of jobs is determined. The resulting frequencies show whether all body requirements can or cannot be met. The difficulty comes in counting up the number of persons available for each combination of jobs. Empirical methods are expensive, time-consuming, and in some cases yield answers of dubious validity because of the instability of the proportions obtained. However, at considerably less cost, estimates of the distribution parameters can be arrived at which give a reasonable fit to joint distributions of variables used for selection purposes. With these relatively stable estimates, and a function which describes reasonably well the personnel supply available, quick and inexpensive estimates of supply of special kinds of personnel can be obtained within reasonable orders of magnitude. The problem becomes one of determining the percent of cases lying simultaneously within specified ranges on a set of variables used for selection. In mathematical terms, find a suitable multivariate function and the regions of interest, and develop the integrals of the function over these regions.

Problems of this sort have been investigated by other research scientists. To date, their efforts have yielded no satisfactory solution, partly because of the particular mathematical statement of the problem. Usually, the approximating function chosen has been the multivariate normal. However, it is difficult to find proportions of cases lying over specified ranges of the normal distribution, since the distribution has no integral which can be written down except as an infinite series. An explicit attempt was therefore made to construct a distribution which gives a reasonably good approximation to the normal and hence a reasonably good approximation to data, but which would be more amenable to manipulation, preferably analytical manipulation. Such a function was constructed and is described in Appendix A. Results were presented at the First Army Operations Research Symposium.

EARLY STAGES IN THE RESEARCH

Another conceptual problem arises from the established practice in Army personnel management of setting minimum standards for entry into advanced training for particular job areas. Such standards may have the advantage of screening out of consideration personnel who may not be suitable for training in a particular specialty. However, such standards may also have the disadvantage of diminishing the potential manpower supply. In some cases, therefore, research is desirable to establish the validity of selectors for predicting performance in future systems. For research purposes it was considered desirable to focus on the problem of ascertaining whether, for a given unfamiliar task, it is desirable to establish minimum prerequisites in terms of aptitude area scores.

The conceptual problem addressed is: Given a set of predictor variables and a scorable criterion, how can any validity present in the entire set of predictor variables be detected? The answer to the question must be sought with the restrictions in mind that research will probably be conducted on prototype equipment--possibly with only one set available--with troops that have to be trained from scratch, in an almost inaccessible location. The goal is to describe the most powerful experiment that can be conducted with a minimum involvement of time, equipment, men and money.

These considerations lead into the investigation of the power of correlation experiments with small samples. The power of an experiment is a term relating to the ability of the experiment to detect real effects when in fact they exist. There is little technology dealing with the power of correlation experiments which may be of use in the practical context of Army research. Literature research, however, revealed that a reasonable set of assumptions has been stated and used in standard contexts, and that the mathematical and computational problems which must be solved for Army personnel management purposes are largely stated. Specifically, the problem is to develop computer routines by which the power of experiments can be calculated, given quantitative estimates of treatment effects considered of sufficient magnitude to warrant policy decisions or changes. The appropriate mathematical functions and desired computations have been identified. However, the values desired are expressible only as an infinite series. To overcome this, it was necessary to state acceptable limits of computational accuracy and develop formulae which are at once feasible and which will yield results within the required accuracy. Such formulae have been developed and are now in preparation for use in programming useful subroutines. The discussion of this problem is quite technical and is summarized in Appendix B.

PROJECTION OF THE FUTURE COMBAT TASK

The first year of existence of the Future Combat Task has resulted in identification of problems relating to information supply and evaluation, as well as identification of research technology which must be developed in order to operate a soundly based program of human factors research for hard-

ware development. It is anticipated that in the coming year, particular human factors problems associated with items or classes of equipment will be identified. This anticipation is supported by the fact that attempts to develop the Handbook initially discussed are leading to contacts with equipment designers, in private industry as well as in government, who are close to the specific items under development. A first draft of the Handbook is expected to be near completion by the close of FY 1963. It is also expected that a library of qualitative and quantitative personnel requirements information on a large number of developmental items will have been assembled.

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APPENDIX A

A MULTIVARIATE DISTRIBUTION FUNCTION

In the Research Study, it was pointed out that a problem existed in finding a multivariate function descriptive of the joint frequency distribution of personnel selection variables and in developing integrals of the distribution over regions of interest. It was also pointed out that so far as approximation is concerned, the multivariate normal distribution is commonly used and is satisfactory. The difficulty comes in attempting to integrate the normal distribution. Hence, in constructing a function suitable for application to the problem at hand, it would seem reasonable that the function should be a close approximation to the multivariate normal with modifications included to insure integrability. Reasoning leading to the choice of a particular function may use the form of the multivariate normal as a point of departure. Let

i, j be subscripts referring to variables

x_i be the i th random variable

u_i be the mean of x_i

c_{ij} be the ij th element of the inverse variance-covariance matrix

k be the number of variables

$N(x_1 \dots x_k)$ stand for the k -variate normal distribution

$$\text{Then } N(x_1, \dots, x_k) = \left(\frac{1}{2\pi} \right)^{k/2} \left| c_{ij} \right| e^{-(1/2) \sum_i \sum_j (x_i - u_i) c_{ij} (x_j - u_j)}$$

Note that all oscillation of the frequency surface is attributable to variation of the quadratic form in the exponent of the multivariate normal. Hence distribution properties of linearity of regression, symmetry, and elliptical lines of equal probability are ascribable to behavior of that quadratic form to generate the frequency surface desired. Note that with increase in the value of the quadratic form the ordinate of the frequency surface decreases--this property, too, will be preserved.

Two critical points are identified: a) use of the quadratic form to determine oscillation of the function, and b) decrease in the function with increase in the value of the quadratic form. The notion immediately suggests itself that by subtracting the quadratic form from a constant, and raising the difference to an integer power, a power series is obtained. Power series are often integrable. Such a function would take the form given below:

$$F(x_1, \dots, x_k) = A \left[K - \sum_i \sum_j (x_i - u_i) c_{ij} (x_j - u_j) \right]^n; \quad \dots$$

$$K > \sum_i \sum_j (x_i - u_i) c_{ij} (x_j - u_j) \quad (1)$$

$$F(x_1, \dots, x_k) = 0 \quad K \leq \sum_i \sum_j (x_i - u_i) c_{ij} (x_j - u_j)$$

Thus $F(x_1, \dots, x_k)$ is a bounded polynomial function which, when expanded yields a power series. By raising the expression in the brackets to the integer power n , continuity in the first $n - 1$ derivatives is assured at the boundaries.

After considerable work on the function (1) a final k -variate form was arrived at as follows:

$$F(x_1, \dots, x_k) = \frac{\prod_{i,j} c_{ij} \Gamma(n+1)}{[(2n+k+2)^{n+k/2} \Gamma(n+k/2+1)]^{k/2}} \cdot \left[2n+k+2 - \sum_i \sum_j (x_i - u_i) c_{ij} (x_j - u_j) \right]^n ; \text{ when}$$

$$2n+k+2 > \sum_i \sum_j (x_i - u_i) c_{ij} (x_j - u_j) \quad (2)$$

$$F(x_1, \dots, x_k) = 0 \quad ; \text{ when } 2n+k+2 \leq \sum_i \sum_j (x_i - u_i) c_{ij} (x_j - u_j)$$

The function (2) has the following useful properties:

1. Linearity of regression
2. Symmetry around the regression lines
3. Marginal distribution of the same form
4. The sample average is an estimate of u .
5. The parameters c_{ij} are the elements of the inverse variance-covariance matrix.
6. The only parameters involved are derivable from the first moments and the second moments and cross moments, with the exception of n .
7. Elliptical lines of equal probability obtain
8. The function approaches the Gaussian normal curve function as n approaches infinity.

These properties and the development of the function will be discussed more in detail in a Technical Research Note in preparation. In the present context, a brief description of the integrability of the distribution will be useful. Consider a sequence of boundaries

$$b_k + \sum_{i=1}^{k-1} b_{ik} X_i \leq X_k \leq a_k + \sum_{i=1}^{k-1} a_{ik} X_i \quad (3.1)$$

$$b_{k-1} + \sum_{i=1}^{k-2} b_{i,k-1} X_i \leq X_{k-1} \leq a_{k-1} + \sum_{i=1}^{k-2} a_{i,k-1} X_i \quad (3.2)$$

$$\vdots$$

$$b_2 + b_{12} X_1 \leq X_2 \leq a_2 + a_{12} X_1 \quad (3.k-1)$$

$$b_1 \leq X_1 \leq a_1 \quad (3.k)$$

The boundaries are intended to define a convex polyhedron set contained within that part of the real K -space for which $F(x_1 \dots x_k) \neq 0$. Since the function (2) is a power series, it may be integrated over x_k and the limits (3.1) substituted. The resulting function will again be a power series in $x_1 \dots x_{k-1}$. One may then integrate over x_{k-1} and substitute the limits (3.2) to obtain another power series in $x_1 \dots x_{k-2}$. This procedure may be repeated until the integration of all the limits is complete. The conclusion is that the function may be integrated over the region defined by a set of planes. This result is sufficient to establish the potential utility of the function for analytical work in investigating manpower supplies.

APPENDIX B

USING THE NON-CENTRAL F DISTRIBUTION TO DETERMINE THE POWER OF A SIGNIFICANCE TEST

A problem of research methodology pertinent to the work of the Future Combat Task has been stated in the Research Study as follows: Given a set of predictor variables and a scorable criterion, how can any validity present in the entire set of predictors be detected? This is an extremely broad question with varied consequences for the research design. The technical problem examined herein, which is only part of the problem, is to detect validity where experimental samples are small. To develop feasible experiments it would probably be necessary to sample selectively on the predictor variables; a suitable mathematical model by which to guide the inferential procedure would be the classical linear regression model with homoscedastic, independent, normally distributed errors of estimate, and with fixed independent variables. Under this situation, it is pointed out by Anderson (1958) that the quantity

$$F = \frac{R^2(1-R^2)}{(N-p)/(p-1)}$$

is distributed as a non-central F distribution with $p - 1$ and $N - p$ degrees of freedom. In this distribution, R is the multiple correlation coefficient, N is the sample size, and p is the number of predictor variables. In addition, there is a somewhat more complex parameter which is called a non-centrality parameter. This parameter is zero if the multiple correlation is zero, positive otherwise varying monotonically with the size of the squared multiple correlation.

The non-central F distribution may be used to determine a sample size required to detect a universe correlation of a given size, provided computational feasibility obtains. As indicated in the main body of the present study, however, the distribution itself is an infinite series. Consequently, computation procedures must be established which allow the use of a series of finite length. Tang (1938) has indicated the possibility of such a procedure. In working a similar but more limited problem, he needed only 20 terms. This would put the solution to the problem easily within bounds of computing equipment available to USAPRO.

To delineate the specific problem at hand, it will be useful to review quickly some facts about hypothesis testing. In both analysis of variance and testing multiple correlations, the test as to whether a given treatment effect or correlation is zero is given by calculating a statistic distributed as a central F if the null hypothesis holds, and checking whether that statistic could reasonably have been drawn from such a distribution. This checking takes the form of observing whether the statistic calculated exceeds a value which would not be exceeded by some prespecified percent of replications of the experiment. For example, if the statistic exceeds an F which would be exceeded on only 5% of a large number of replications of the experiment, then the central F distribution is probably not appropriate and the decision is usually in favor of the non-central F. If by sheer bad luck the observed statistic exceeds the predetermined value when it really usually would not, the experimenter would make an error of inference of the first type, that is, he would conclude that a real effect exists where in fact it does not.

Similarly, it is possible to decide that an effect does not exist when in fact it does. This is called an error of the second type. In this case, the test would amount to finding a statistic that really is drawn from a non-central F distribution, in a range of values acceptable as a central F. The problem therefore is, given a particular non-central F distribution, what is the probability of observing an F equal to or less than the upper limit of the range acceptable as a central F?

Mathematically, the problem is to develop an expression for the integral from zero up to some prespecified value over a given non-central F distribution, and calculate the numerical value of the resulting function. Tang (1938) has developed an integral which has this same numerical value, which is given below,

$$P(II) = \sum_{i=0}^{\infty} \frac{\lambda^i e^{-\lambda}}{i!} I_L \left(\frac{f_1}{2} + i, \frac{f_2}{2} \right) \quad (1)$$

where λ is the non-centrality parameter, f_1 and f_2 are the degrees of freedom and I is a function of the upper limit of integration. The function

$I_L \left(\frac{f_1}{2} + i, \frac{f_2}{2} \right)$ is the Incomplete Beta which has been tabled by Karl Pearson

(1932). Thus, if the number of terms of the form given in (1) needed for evaluation of the probability of the error of the second kind, P_{II} , within

reasonable computation accuracy is finite, the function can be evaluated using table look-up procedures for the Incomplete Beta. To obtain the number of terms, note that the Incomplete Beta is always equal to or less than one, and that the remainder of the expression in a term of the series is a Poisson term. Hence, if only the first b terms were used, the remainder, which would constitute the error, would relate to a sum over comparable terms of a Poisson series as follows:

$$\sum_{b+1}^{\infty} \frac{\lambda^i e^{-\lambda}}{i!} \geq \sum_{b+1}^{\infty} \frac{\lambda^i e^{-\lambda}}{i!} I_L \left(\frac{f_1}{2} + i, \frac{f_2}{2} \right)$$

Thus it is seen that the partial sum of the Poisson series is an upper bound on the error of approximation. One would therefore procede as follows:

a. set E equal to the maximum tolerable error,

b. find b such that $\sum_{b+1}^{\infty} \frac{\lambda^i e^{-\lambda}}{i!} \leq E$
by finding a b for which $\sum_{i=0}^b \frac{\lambda^i e^{-\lambda}}{i!} \geq 1 - E$

c. compute $P(II)$ as follows:

$$P(II) = \sum_{i=0}^b \frac{\lambda^i e^{-\lambda}}{i!} I_L \left(\frac{f_1}{2} + i, \frac{f_2}{2} \right)$$

The procedure given in step b. above arises from the fact that the complete sum of the Poisson series is equal to one. The computational procedure suggested is needed to give a finite range to the subscript.

This procedure and useful elaboration of it are under study for construction of Fortran computer routines for the IBM 7090. It is anticipated that the routines will be completed during FY 1963, and that concrete results on the power of correlation experiments will be published. With the completion of this activity, determination can be made of sample sizes required to detect predictive value of practical importance. It is planned that the routines developed will be supplied to publications which have rather broad distribution both within and without government.